A NOTATION SYSTEM FOR THE DESCRIPTION OF BEHAVIORAL PROCEDURES[1]

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One characteristic shared by all behavior experimentation is that stimuli are presented to a subject according to pre-designed rules. These rules are variously called conditioning procedures, behavioral procedures, reinforcement contingencies, or reinforcement schedules. While behavioral investigations may differ widely with regard to the rigor of specification as well as the nature of the stimuli they employ (even the term stimulus is far from universal), the rules or conditions that govern the presentation of these stimuli must always in some way be conveyed in reporting the work. The purpose of this paper is to propose a notation for the description of these rules.

In published papers they are most frequently described by circumlocution, a method of communication which may require anywhere from several sentences to several pages of text, depending on the author's style and the complexity of the rules concerned. On occasion, authors dissatisfied with the inelegance and verbosity of this mode of description have also devised special notations suitable for their own particular needs. One drawback of such specialized notations has always been, however, that their usefulness tends to be restricted to the applications for which they were designed. The notation system proposed in the present paper represents an attempt to satisfy a wide-enough range of requirements to make it a reasonable first approximation to a generally useful system for describing the essential features of behavioral procedures by means of symbolic diagrams. It is essentially an amalgam of four other notations that are in current use: (1) the one traditionally used in psychological paradigms to describe the succession of stimuli and responses; (2) the flow-chart notation widely used in electronics, computer programming, and systems engineering; (3) the notation of Boolean algebra, which has found its main applications in set theory and logic; and (4) the notation of mathematics.

The history of science bears testimony to the fact that the advent of a good notation can have effects beyond merely expediting communication. The symbolic notation of chemistry, for example, served as a catalyst for the development of theory in providing a framework within which existing knowledge could be systematized. It is possible that in behavioral science a successful notation, whether it be the present one or some other, could play an analogous role in the classification of procedures. By presenting a set of intricate interrelations in a concise and schematic form, a diagrammatic or symbolic notation can often lay bare the essential structural features of these interrelations, thereby facilitating their analysis. Thus, a good notation system could implement the discovery of formal parallels between behavioral procedures, and generally suggest schemes for their classification.

DEFINITIONS OF SYMBOLS

Stimuli, Responses, and Time Intervals

The symbols used to designate stimuli, responses, and time intervals are the usual abbreviations S, R, and T, respectively. These symbols and the various modifiers they require

[1]The author wishes to thank W. N. Schoenfeld and A. G. Snapper for their helpful comments and suggestions.

were chosen, insofar as possible, in accordance with existing conventions, and are in that sense arbitrary. They are merely the vocabulary of the notation system, not its syntax; they designate events rather than relationships. Although the list of symbols given below may be adequate for the behavioral procedures considered in this paper, it will undoubtedly have to be supplemented to handle unanticipated requirements of new applications. Such supplementation would not constitute a serious modification of the present system and should be resorted to freely.

R_A A response of type A (e.g., a response on lever A).
R_B A response of type B (e.g., a response on lever B).
R^m A response of magnitude m (m can refer to force, power, velocity, duration, or any other intensive dimension).
nR n responses.
vnR A variable number of responses. The mean number is n.
T A time interval of length T.
vT A time interval of variable length and average length T.
S^R A reinforcing stimulus.
S^m A stimulus of magnitude m. (Here, m could refer to intensity, frequency, power, loudness, etc.)
S_i Stimulus, or stimulus complex, of type i.

The Relationship Symbols

The notation system has four symbols which designate relationship. They are:

(1) The horizontal arrow connecting two events, e.g., $A \longrightarrow B$

(2) The bracket around vertically listed conditions, e.g., $\left[\begin{array}{l} A \longrightarrow B \\ C \longrightarrow D \end{array}\right.$

(3) The vertical arrow cutting a horizontal arrow, e.g., $\left[\begin{array}{l} A \longrightarrow B \\ C \end{array}\right.$

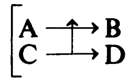
(4) The intersection symbol $\cap$.

The Horizontal Arrow. The horizontal arrow indicates temporal succession of the events it connects. It can be read in either of two ways, depending on whether it leads to a stimulus or to a response. When it leads to a stimulus, as in the expression $R \longrightarrow S$, the arrow is read as "produces"; when it leads to a response on the other hand, as does the first arrow in the expression $R_A \longrightarrow R_B \longrightarrow S$, it cannot be read as "produces," since a response cannot be said to "produce" another response. Here, it must be read as "produces a condition where," and the entire expression would accordingly be read as "R_A produces a condition where R_B produces stimulus S." The horizontal arrow must, therefore, be read either as "produces" or as "produces a condition where," according to whether it leads to a stimulus or to a response.

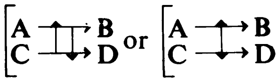
The Bracket. Conditions written in a vertical relationship to each other inside a bracket go into effect simultaneously. The expression $R_A \longrightarrow \left[\begin{array}{l} R_B \longrightarrow S^R \\ S \end{array}\right.$, for example, would mean that a response of type A produces two simultaneous conditions: $R_B \longrightarrow S^R$ and S. The simultaneity of these conditions is shown by their vertical superposition inside the bracket. The entire expression would be read as "response A produces stimulus S simultaneously with a condition where response B produces reinforcement." The height at which the arrow from R_A meets the bracket is, of course, of no significance, since the vertical rank of the conditions listed inside the bracket is arbitrary. It should be noted that vertical superposition *per se* does not indicate temporal simultaneity; it does so only when the vertically superposed conditions are against a bracket. So, if two chains of conditions are written inside a bracket, only the first members of these chains are necessarily simultaneous. Subsequent members may or may not be simultaneous, depending on the relative speeds with which the chains progress.

The Vertical Arrow. A vertical arrow cutting a horizontal arrow indicates that the event at which the vertical arrow originates prevents the succession denoted by the horizontal arrow. Below are listed some of the interrelationships that require the vertical arrow for their description. The letters in the illustrative diagrams could stand for responses, stimuli, or time intervals.

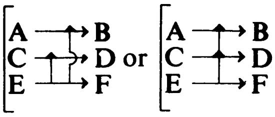
(1) C produces D and prevents A from producing B.



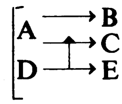
(2) C, if it occurs before A, produces D
and prevents A from producing B.
If A occurs before C, then A produces B
and prevents C from producing D.



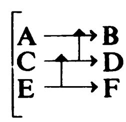
(3) E produces F and prevents A from producing B
and C from producing D.



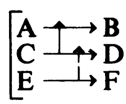
(4) D produces E and prevents A from producing C,
but does not prevent A from producing B.



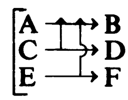
(5) If C occurs before E, it produces D
and prevents A from producing B.
E produces F and prevents C from producing D,
and also C from preventing A from producing B.



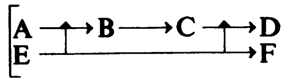
(6) C prevents A from producing B.
If it occurs before E, it also produces D.
E produces F and prevents C from producing D.



(7) C, if it occurs before A, produces D
and prevents A from producing B.
E, if it occurs before A, produces F
and also prevents A from producing B.



(8) E, if it occurs before A, prevents B
and consequently also C and D.
If E occurs after B and before C,
it does not prevent B from producing C,
but does prevent C from producing D.
If E occurs after C and before D,
it prevents C from producing D.
In all these cases, E produces F.



In all the above examples, the vertical arrow is shown as branching off a horizontal arrow. Whether it is drawn in this way or as a separately originating arrow (e.g., $\left[\begin{array}{l} A \xrightarrow{\uparrow} B \\ C \longrightarrow D \end{array}\right.$) is arbitrary and should depend on the features of the diagram the author wishes to emphasize.

The Intersection Symbol. The intersection symbol $\cap$ indicates that both of two conditions written on either side of it must be met. The expression $R_A \cap R_B \longrightarrow S^R$, for example, would mean that both of two possible responses, R_A as well as R_B, are required for reinforcement. This requirement could also be denoted without using the intersection symbol by showing that either R_A followed by R_B, or R_B followed by R_A, produces reinforcement, as follows: $\left[\begin{array}{l} R_A \longrightarrow R_B \xrightarrow{\uparrow} \\ R_B \longrightarrow R_A \xrightarrow{\downarrow} \end{array}\right. S^R$. The reciprocal vertical arrows indicate that once either sequence has occurred the other is no longer effective, so that only one reinforcement can be obtained. Since this alternative notation is available, the intersection symbol should be regarded as an abbreviation, definable in terms of the three other symbols discussed above.

Some Rules for Stimulus Notation. The term stimulus, which will be used interchangeably with such terms as stimulus complex or stimulus situation, will always refer to some aspect of the animal's environment which is under experimental control. The controversy over whether or not a physical change should be called a stimulus if the animal has not learned to discriminate it is deliberately sidestepped. Also of no concern here is the epistemological status of such concepts as response-produced stimuli and hypothetical stimulus elements. Neither of these issues has any bearing on the problem of describing procedures.

The rules presented below were designed to simplify the problems of stimulus notation encountered in the behavioral procedures considered in this paper. The application of these rules had the effect of eliminating many ambiguities and complexities that other possible rules entailed.

(1) The symbol S_i refers to the entire prevailing stimulus complex i. The composition of this stimulus complex would be described separately and not within the diagram proper. For example, if an experiment involved four different stimulus conditions, these would be denoted in the diagram as S_1, S_2, S_3, and S_4, and might be described in a separate text as corresponding to "tone on, light off," "tone on, light on," "tone off, light on," and "tone off, light off," respectively. A more precise physical specification of these stimulus complexes would also be given in the separate text. Accordingly, all stimuli (or stimulus complexes) are mutually exclusive, and only one can prevail at any one time.

(2) If a single stimulus change is specified, then two stimulus symbols are required, since both the stimulus complex that prevailed before the change, as well as the new stimulus complex, must be denoted.

(3) A stimulus change is indicated by simply specifying the presentation of the new stimulus. The last indicated stimulus always replaces the current one, and remains present until a further stimulus change is specified. The general schema for indicating stimulus changes is, accordingly, $\left[\begin{array}{l} A \\ S_1 \end{array}\right. \longrightarrow \left[\begin{array}{l} B \\ S_2 \end{array}\right. \longrightarrow \left[\begin{array}{l} C \\ S_3 \end{array}\right. \longrightarrow \left[\begin{array}{l} D \\ S_4 \end{array}\right.$. Each of the letters A, B, C, and D stands for some condition which specifies when the stimulus with which it is concurrent is to be replaced by the succeeding stimulus. Each stimulus remains present until it is replaced by its successor.

The Notation of Time Intervals. The symbol T denotes the length of the time interval to which it refers. It is only used, however, when a procedure is stated in its general form. In the description of any specific procedure, the symbol T would be replaced by the actual value of the time interval employed, such as 10 seconds or 5 minutes.

A condition which follows a horizontal arrow leading from a time interval goes into effect at the moment the time interval terminates. If the termination of the time interval produces a stimulus change, the notation is $\left[\begin{array}{l} T_1 \longrightarrow S_2 \\ S_1 \end{array}\right.$; if it produces a condition where a response will have a certain consequence C, the notation would be $T_1 \longrightarrow R \longrightarrow C$. To show that a condition which goes into effect at the end of time interval T_1 is to remain in effect for only a limited time, the limiting time interval, say T_2, is written in a vertical relation to that condition. In the above case, for instance, the duration of S_2 could be specified by showing that it is to be replaced after T_2 seconds by a new stimulus S_3, as follows: $\left[\begin{array}{l} T_1 \longrightarrow \\ S_1 \end{array}\right. \left[\begin{array}{l} T_2 \longrightarrow S_3. \\ S_2 \end{array}\right.$

THE DESCRIPTION OF PROCEDURES

Recycling Arrows

When a succession of conditions repeats or recycles, this may be shown by a horizontal arrow which begins at the end of the sequence and leads back to its beginning. It is often necessary to indicate, for example, that after a reinforcement the entire sequence that led to reinforcement can be repeated. This is true in the fixed-ratio schedule (Skinner, 1938), where every nth response is reinforced. The notation for fixed ratio would accordingly be $\hookrightarrow nR \longrightarrow S^R \lrcorner$. Another familiar procedure requiring the recycling arrow is fixed interval (Skinner, 1938), where every reinforced response initiates a new time interval after the end of which a response can again be reinforced. Here, the notation would be $\hookrightarrow T \longrightarrow R \longrightarrow S^R \lrcorner$

It should be noted that the notation for reinforcement, S^R, is actually an abbreviation. Strict observance of the rules for stimulus notation would require denotation of the stimulus complex that prevails when S^R is not present, and also a specification of the conditions that control the duration of S^R. The complete, unabbreviated fixed-ratio diagram would, accordingly, be $\hookrightarrow \left[\begin{array}{l} nR \longrightarrow \\ S_1 \end{array}\right. \left[\begin{array}{l} E \\ S^R \end{array}\right. \lrcorner$, where S_1 is the stimulus complex when reinforcement is not being presented and E is the reinforcement-terminating event. The nature of this reinforcement-terminating event depends on the type of reinforcement used and the manner of its presentation. If the reinforcement is a pellet in a food dish, the reinforcement-terminating event would be the consumatory response. If the reinforcement consists of access to a grain hopper or dipper cup, the reinforcement-terminating event would be the end of the time interval that determines duration of access. In either case, S_1 is the stimulus situation that prevails when reinforcement is not being presented. The restoration of this stimulus situation is contingent upon the occurrence of E.

Since the nature of the reinforcement episode is usually not of sufficient interest to warrant complicating the diagram with a precise description of it, the abbreviation $\longrightarrow S^R$ will henceforth be used in place of the more complete $\left[\begin{array}{l} E \longrightarrow S_1 \\ S^R \end{array}\right.$. With this abbreviation, the recycling arrow can originate either at the reinforcement-producing event (e.g., $\hookrightarrow R \longrightarrow S^R$), or at the reinforcing stimulus ($\hookrightarrow R \longrightarrow S^R$). The two forms are simply different ways of writing the abbreviation, and are equally arbitrary. The form where the recycling arrow begins at reinforcement will be the one used in this paper.

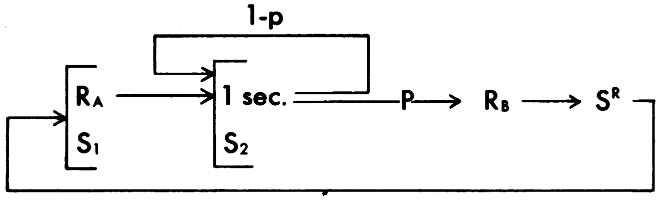
The recycling arrow is also required in situations where some condition repeats according to a fixed time cycle. One well-known example of such a situation is classical conditioning. A procedure where stimulus S_1 comes on for T_1 seconds at the end of which a shock S_2 of of T_2 seconds' duration is delivered would be written as $\hookrightarrow \left[\begin{array}{l} T_1 \\ S_1 \end{array}\right. \longrightarrow \left[\begin{array}{l} T_2 \\ S_2 \end{array}\right. \longrightarrow \left[\begin{array}{l} T_3 \\ S_3 \end{array}\right.$. T_3 would be the intertrial interval and S_3 the intertrial stimulus complex.

An example of a continuously recycling time interval is provided by a schedule described by Schoenfeld, Cumming, and Hearst in 1957. In one version of this schedule, the first response occurring in every time interval T is reinforced: $\hookrightarrow \left[\begin{array}{l} T \\ R \longrightarrow S^R \end{array}\right.$. It should be noted that the expression $R \longrightarrow S^K$ is recycled only upon the termination of T, so that only one response in each T can be reinforced. If it were desired to indicate that more than one response is to be reinforced in any one period T, then $R \longrightarrow S^R$ would be shown as recycling upon itself.

In general, it should be understood that a succession denoted by a horizontal arrow can occur only once, and cannot be repeated until the condition has been reinstated by another event. For example, the expression $R \longrightarrow S^R$ means that one response is reinforced, and not that every response is reinforced. The latter case would require a recycling arrow from S^R back to R, to reinstate the original condition after a reinforcement has been obtained.

The Notation for Probability of Succession

Sometimes, it is necessary to indicate that two events follow each other not invariably, but according to a certain probability controlled by the experimenter. This is done by writing the probability of the succession over the horizontal arrow—a notation borrowed from information theory. One procedure requiring this notation is the one developed by Brandauer (1958), where every response has the same probability of being reinforced. The notation for this procedure would be $\hookrightarrow R \xrightarrow{p} S^R$. Several other procedures which require the probability notation for their description are currently being investigated at Schering Corporation. In one of these, every R_A has a certain probability p of producing a condition where R_B will be reinforced, $\hookrightarrow R_A \xrightarrow{p} R_B \longrightarrow S^R$. In a related procedure, the probability of $R_B \longrightarrow S^R$ going into effect is governed by the passage of time. Once R_A has been made, the probability that $R_B \longrightarrow S^R$ will go into effect at the end of any given 1-second period is p. If the $R_B \longrightarrow S^R$ condition does not go into effect at the end of any 1-second period, the period recycles, and continues to do so until the $R_B \longrightarrow S^R$ condition finally does go into effect.



(1)

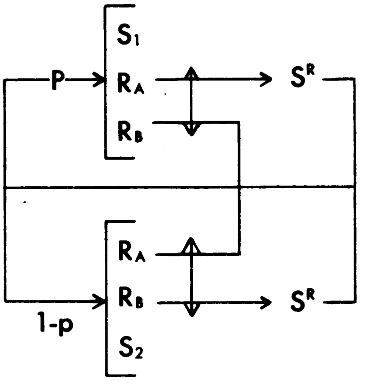
The recycling probability of the 1-second interval is 1-p, the complement of p, rather than 1.00, because this interval recycles only if $R_B \longrightarrow S^R$ did not go into effect. Once the $R_B \longrightarrow S^R$ condition has gone into effect, the next R_B is reinforced, following which the entire sequence recycles, so that S_2 and its associated contingencies can be restored only by an R_A.

These procedures can also be described by means of an alternative notation which does not involve the use of the probability symbol. By this alternative notation, the $R_A \xrightarrow{P} R_B \longrightarrow S^R$ procedure would be written as $vNR_A \longrightarrow R_B \longrightarrow S^R$. N is the average number of R_A's required to bring about the $R_B \longrightarrow S^R$ condition, and the symbol v indicates that the actual number varies from one trial to the next. The alternative notation for the procedure shown in diagram (1) above would be $\begin{matrix} R_A \\ S_1 \end{matrix} \longrightarrow \begin{matrix} vT \\ S_2 \end{matrix} \longrightarrow R_B \longrightarrow S^R$

Again, T is the average length of time before $R_B \longrightarrow S^R$ goes into effect, and v indicates that the interval varies from one trial to the next.

When this notation is used, the diagrams have to be supplemented with a separate statement of the rule or distribution according to which N or T vary around their means. When the probability notation is used, on the other hand, the means as well as the distribution according to which N and T vary around their means are completely specified when the values of p are given. This is so because the resulting distribution is the Poisson distribution, whose only parameter is p. It must be conceded, however, that the alternative notation, although less elegant for the particular examples chosen, is likely to be the more generally useful one. There are many variable schedules currently in use for which the probability of $R \longrightarrow S^R$ going into effect changes in such a complex way, as a function of either time or number of responses, that a complete mathematical specification of this change within the diagram would render the diagrammatic notation unwieldy. In those cases, it will, therefore, be simpler merely to indicate in the diagram the value of the mean of the quantity together with the fact that it varies from one reinforcement to the next, and to reserve the precise specification of the rule according to which it varies for a less constrained presentation.

The probability symbol can also be used to indicate the relative probabilities of a set of experimental conditions or procedures to which the subject may be exposed on any given trial. These relative probabilities would be written over the arrows that indicate the initiation of the various alternative conditions. In the *Y*- or *T*-maze, successive-discrimination procedure, for example, either of two alternative stimulus situations, S_1 or S_2, may confront the animal at the choice point. The animal also has two possible responses, R_A (e.g., turning right) and R_B (turning left). If stimulus complex S_1 (e.g., positive stimulus on the right and negative stimulus on the left) prevails, then R_A will be reinforced and R_B will not. If, on the other hand, stimulus complex S_2 (negative stimulus on the right and positive stimulus on the left) prevails, then R_B will be reinforced and R_A will not. After every trial the animal is returned to the choice point, and the probabilities that S_1 or S_2 will prevail on the next trial are p and 1-p, respectively. This procedure is described by the following diagram:



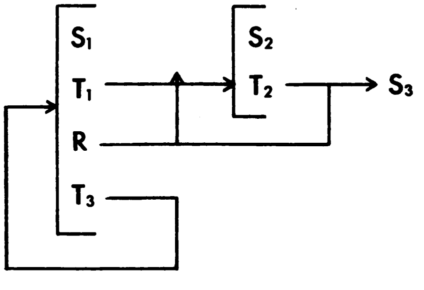
(2)

The reciprocal vertical arrows between the horizontal arrows from R_A and R_B are needed to show that once either of the two responses has occurred, the other one cannot have its indicated consequence until all the conditions within the bracket have been reinstated by the recycling arrow.

Uses of the Vertical Arrow

In behavioral procedures, a prevailing condition is often terminated by a specified event. Examples of this are escape conditioning, where a response terminates an aversive stimulus, limited-hold procedures (Ferster & Skinner, 1957), where a reinforcement condition is terminated at the end of a time interval, and the various reset procedures, in which a response resets a time interval or an accumulated count. The symbol used to indicate that an event prevents a succession is a vertical arrow which starts from this event and cuts the horizontal arrow that designates the succession.

The Warner avoidance procedure (Warner, 1932) is a familiar example of a situation where a response prevents something. A warning stimulus S_1 is presented and a shock S_2 is delivered T_1 seconds later unless a response has occurred during those T_1 seconds. If the shock is delivered, it can be terminated (escaped) by a response. The notation for this procedure would be:

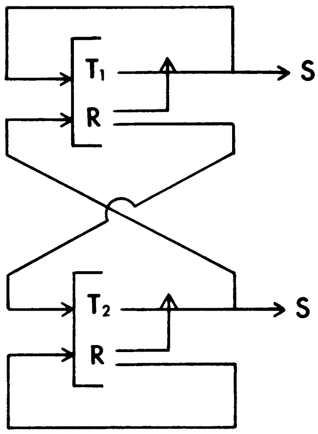


(3)

T_1 is the duration of the warning stimulus S_1, T_2 is the duration of the shock S_2, and S_3 is the prevailing stimulus complex when neither S_1 nor S_2 is present. T_3 is simply the period with which these conditions recycle. S_3, once it has been specified, remains present for the balance of T_3, that is, until S_1 is reintroduced by T_3's recycling. (It will be recalled that when a new stimulus is specified it replaces the prevailing stimulus.) If R occurs during T_1 it prevents S_2 (shock) and produces S_3, thereby terminating the warning stimulus S_1. If R occurs during the shock S_2 it also produces S_3 and thereby terminates the shock.

If it were desired to indicate that the shock, once it has begun, is inescapable, an additional vertical arrow from T_1 cutting the $R \longrightarrow S_3$ arrow would be required. This way, the response would be unable to produce S_3 after the termination of T_1, and the shock would last for its full T_2 seconds, regardless of any responses that may occur during it.

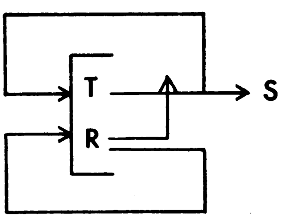
In the Sidman avoidance schedule (Sidman, 1953), a response prevents a time interval from ending with a shock, and also resets the interval. If the shock-shock interval and the response-shock interval are designated by T_1 and T_2, respectively, and the shock is denoted by S, the procedure would be written:



(4)

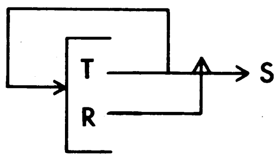
It will be noted that the symbol for shock, $\longrightarrow S$, is an abbreviation in the same sense as the symbol for positive reinforcement, $\longrightarrow S^R$, discussed earlier.

The diagonal crossing arrows emphasize the inherent logical symmetry of the procedure. A response prevents the time interval during which it occurs from terminating with a shock, and initiates time interval T_2. If either time interval is permitted to terminate, however, a shock is delivered and time interval T_1 is initiated. It should be noted that the vertical arrows from the responses cut the horizontal arrows from the time intervals at a point along the arrow where *both* the shock as well as the recycling of T_1 are prevented. If the two intervals T_1 and T_2 happened to be of the same length, the diagram would reduce to:



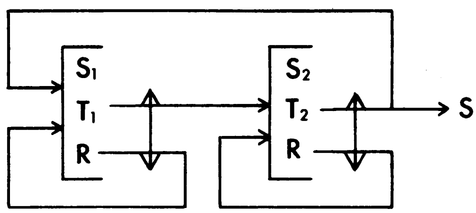
(5)

In a modified version of the Sidman procedure, which is currently in use at Schering Corporation, a response merely prevents the current time interval from ending with a shock, but does not recycle it. The time interval recycles only upon its termination, independently of any responses that may occur. Here, the vertical arrow from the response is shown as cutting the horizontal arrow from T after, rather than before, the point where the recycling arrow branches off:



(6)

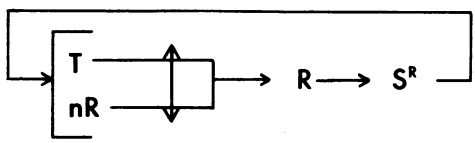
Another procedure devised by Sidman (Sidman, 1957) calls for reciprocal vertical arrows between the responses and the time intervals during which they occur. In this procedure, S_1 comes on after every shock and remains on until a period of T_1 seconds has passed without the occurrence of a response, at which time it is replaced by S_2. Then, S_2 remains on until a period of T_2 seconds has passed without the occurrence of a response, at which time a brief shock S is delivered and S_1 is restored. The diagram of this procedure is:



(7)

The vertical arrows from the responses indicate, as they did in the previous examples, that the shock at the end of the time interval in which the response is made will not be delivered. The vertical arrows from the time intervals, on the other hand, must be shown in order to eliminate the ambiguity as to which of the two time intervals, T_1 or T_2, is recycled by any given response. Without these arrows, a single response could be interpreted as recycling both time intervals.

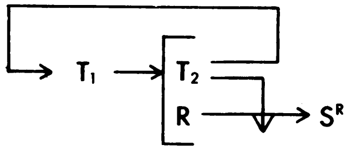
Reciprocal vertical arrows are also required in the alternative schedule described by Ferster and Skinner (1957) in which a response is reinforced either after a time interval T has elapsed or after n responses have been made, whichever occurs earlier. The diagram for this procedure is:



(8)

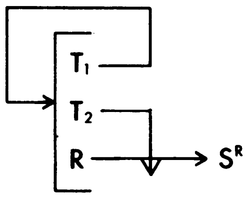
If the reciprocal vertical arrows were omitted, the diagram would, of course, mean that a response can be reinforced *both* after n responses and also after time interval T has elapsed.

Schoenfeld's procedure (Schoenfeld et al., 1957) provides an example of a limited-hold contingency. Here, a time interval recycles continuously, but the $R \longrightarrow S^R$ condition is in effect only during the first T_2 seconds of this interval. The fact that the $R \longrightarrow S^R$ condition terminates when T_2 ends is shown by a vertical arrow from T_2.



(9)

An alternative notation for this procedure is:

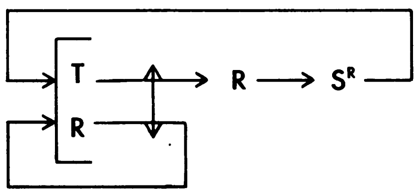


(10)

where $T_2 < T_1$

Here, again, only the first response in T_2 is reinforced, since $R \longrightarrow S^R$ is not shown as recycling.

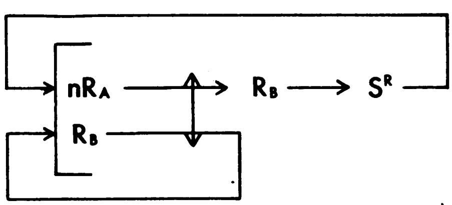
The best-known of the currently used reset procedures is the DRL schedule (Wilson & Keller, 1953; Ferster & Skinner, 1957). A response, in order to receive reinforcement, must follow the preceding response by the minimum prescribed time interval. The diagram is:



(11)

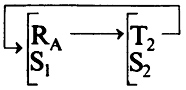
If the vertical arrow were omitted, a response occurring before the end of time interval T would start a new time interval but would not prevent the $R \longrightarrow S^R$ condition from going into effect at the end of the current interval.

The so-called counting procedure (Mechner, 1958) presents a similar problem. An R_B is reinforced only if it follows n consecutive R_A's. If an R_B occurs prior to the completion of n consecutive R_A's, the count recycles, and a new series of n R_A's is required. The diagram for this procedure is:

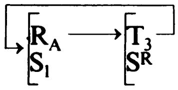


(12)

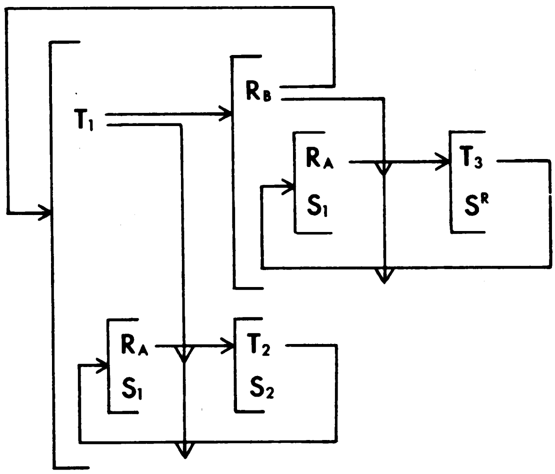
Because of the rule that no two stimuli may be present simultaneously, it is not necessary to indicate explicity by means of a vertical arrow that an event which produces a new stimulus also terminates the current stimulus. The same is not true for conditions other than stimuli, however, where there is no rule barring coexistence. In Holland's detection-of-deflection procedure (1957), for example, every response occurring before the end of T_1 produces a stimulus S_2, a brief illumination of a dial whose pointer is undeflected. After the end of T_1, every response produces another stimulus, S^R, a brief illumination of the dial with the pointer deflected. (The reinforcing effect of this stimulus is a consequence of the instructions the subject was given.) In this procedure it is necessary to indicate that the



condition terminates at the end of T_1, at which time it is replaced by the

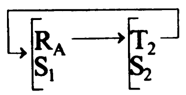


condition. This would be shown as follows:



(13)

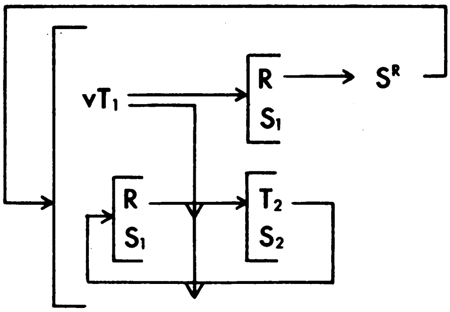
The vertical arrow from T_1 must be shown as cutting both horizontal arrows in the



circuit. If the horizontal arrow from T_2 were not cut, the following situation could arise: T_1 terminates during T_2, and changes S_2 to S_1; an R_A occurs before T_2 has elapsed, and produces S^R; T_2 terminates while S^R is still present, that is, during T_3, and changes S^R back to S_1. If this happened, S^R would not be presented for its intended duration. The arrow from T_2 to S_1 must therefore be cut when T_1 terminates. The two vertical arrows from R_B must be shown in order to preclude an analogous possibility when the conditions are recycled by an R_B.

It will be noticed that detection of deflection is built around the skeleton of the fixed-interval procedure, $T \longrightarrow R \longrightarrow S^R$. It contains two elaborations that are lacking in the basic fixed-interval diagram. One is the specification that every response prior to the termination of T_1 produces a flash of S_2; and the other is the fact that every response after the termination of T_1 produces a brief presentation of the reinforcing stimulus and continues to do so until the "consumatory" response R_B is made.

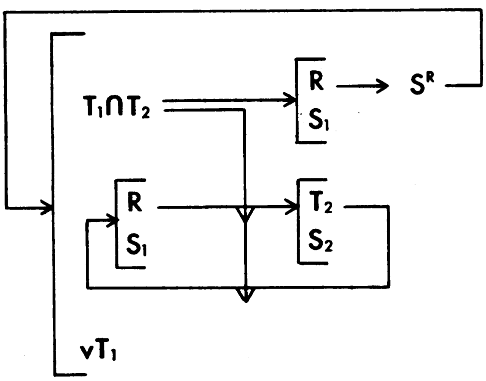
Morse and Skinner (1957) have devised a procedure which has some formal similarities to detection of deflection. Instead of producing only a brief flash of S_2, every response prior to the end of the time interval T_1 produces a stimulus which remains on for 5 seconds (T_2). If the variable interval T_1 happens to end during one of these 5-second periods, S_1 replaces S_2, and the $R \longrightarrow S^R$ condition goes into effect:



(14)

The Use of the Intersection Symbol and of Cross-reference Within a Diagram

A question now arises as to how one would describe the procedure where S_2 is *not* replaced by S_1 the moment T_1 terminates, but remains present for its full 5 seconds (T_2), and where the $R \longrightarrow S^R$ condition does not go into effect until both T_1 *and* T_2 have terminated. (Morse has investigated this procedure, too.) For its description, the logical intersection symbol $\cap$ is required. By means of this symbol one can show that both of two conditions, the termination of T_1 as well as that of T_2, must be fulfilled. The diagram would be:



(15)

It should be noticed that the fact that the reinforced response initiates the next T_1 is indicated by writing vT_1 separately. The expression $vT_1 \cap T_2$ cannot be interpreted as meaning that either T_1 or T_2 begins at the bracket, because of the ambiguity that would ensue. If the interpretation that one of the time intervals begins at the bracket is desired, then this time interval (in the present case, T_1) must be written separately, as is done in the diagram above. This type of cross-reference is one of the important resources of the notation system. When two or more conditions make up a complex (either logical or mathematical) expression, these conditions must be defined elsewhere in the same diagram. The following examples are presented as further illustrations of the use of this device.

In the conjunctive schedule (Ferster & Skinner, 1957; Herrnstein & Morse, 1958), a response is reinforced only after both time interval T has elapsed and *n* responses have been made since the last S^R. Here, again, the intersection symbol is required, and the two components of the intersection must be defined separately. The diagram would accordingly be:

$$\begin{array}{l} nR \cap T \longrightarrow R \longrightarrow S^R \\ nR \\ T \end{array} \qquad (16)$$

In the interlocking schedule, also described by Ferster and Skinner (1957), the condition for reinforcement is defined by a mathematical expression. The number of responses required to produce the $R \longrightarrow S^R$ condition is a function of the time that has elapsed since the last reinforcement. The number of responses must, therefore, be written as a function of this elapsed time:

$$\begin{array}{l} f(t)\,R \longrightarrow R \longrightarrow S^R \\ t \end{array} \qquad (17)$$

The time interval is denoted by a lower-case letter because it is a variable rather than a constant. In case the function f(t) is too unwieldy to be defined in the diagram, it can be defined in a separate statement. This separate statement could either be an equation (e.g., $f(t) = k/t$) or a graphical definition of the kind proposed for this type of schedule by Skinner (1958).

Sidman (1958) devised an avoidance procedure in which every shock initiates a "safe" time interval, at the end of which another shock is delivered. Every response the animal makes increases the length of the safe time by T_1 seconds. In case no responses at all occur, the length of the safe time would be T_2 seconds. To show that the number of T_1's added to T_2 is the number of responses made since the last shock S, the expression nR must be written separately inside the same bracket that marks the initiation of the safe time. This must be done in order to define n. The diagram for the procedure is $\begin{array}{l} nT_1 + T_2 \longrightarrow S \\ nR \end{array}$. The expression $nT_1 + T_2$ gives the time when the next shock is scheduled, and is reckoned from the previous shock. Although the value of the time interval $nT_1 + T_2$ is continuously revised as n increases, the time of initiation of this interval is fixed.

In the next example, which is based on a procedure devised by Lindsley (1957), the intensity of a stimulus changes in discrete steps as a function of responses and the passage of time. Here, the problem is to state in the diagram the rule which specifies each succeeding intensity of this stimulus. Since every intensity increment or decrement is in part a function of the intensity of the stimulus at that moment, this momentary intensity must be a component of the expression which specifies the succeeding intensity. In the example chosen, every response reduces the stimulus intensity by a fixed fraction, for instance, 0.5 of its current value, while every T seconds the intensity is raised by the same fraction of the difference between the maximum possible value and the current value:

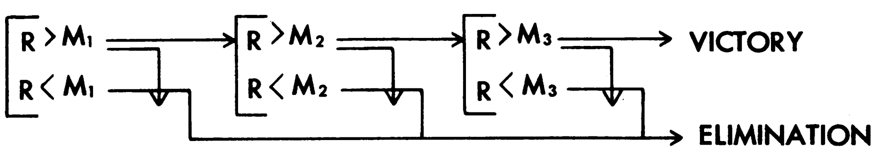
$$\begin{array}{l} \hookrightarrow R \longrightarrow S^{.5\ I_i} \\ \hookrightarrow T \longrightarrow S^{.5\ (I_i + I_{MAX})} \end{array} \tag{18}$$

I_i is the current intensity of the stimulus, and the superscripts of S specify the new intensity of S after a response has occurred or a time interval has terminated.

Procedures Involving the Specification of Response Magnitude

The term magnitude, when applied to a response, may refer to any of its physical dimensions. Examples of possible response magnitude dimensions are force, velocity, power, duration, and amplitude. The use of the term magnitude for all of these should not be taken as an implication that they all have something in common, or even that they are all manifestations of some other, unmeasured, thing. The term merely refers to a scaled attribute of the response.

As was shown in the list of symbols, the magnitude of a response is denoted by its superscript. If the magnitude of a response is specified as having to be above, below, or within certain limits, the symbols "greater than" or "less than" are used in the superscript. For example, a procedure where any response whose magnitude falls within the limits M_1 and M_2 is reinforced would be written $\hookrightarrow R^{M_1 < m < M_2} \longrightarrow S^R$. Because of the paucity of behavior research involving response magnitude, no procedures have as yet been devised that would put this magnitude notation to a more stringent test. Examples of situations whose analysis requires the specification of response magnitude may, however, be found outside the laboratory. For instance, an elimination tournament, where the winners of each round play each other in the next while losers are eliminated, can be thought of as a situation where responses of gradually increasing magnitude are required. This would be written:

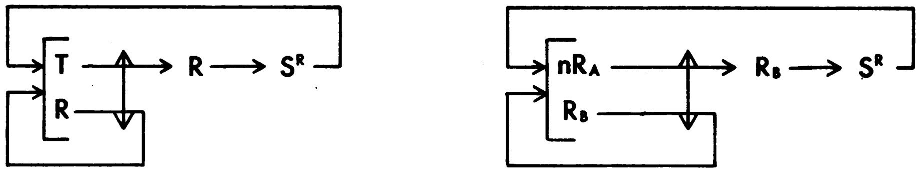


(19)

The real test of this notation will, however, have to await further research in the response magnitude area.

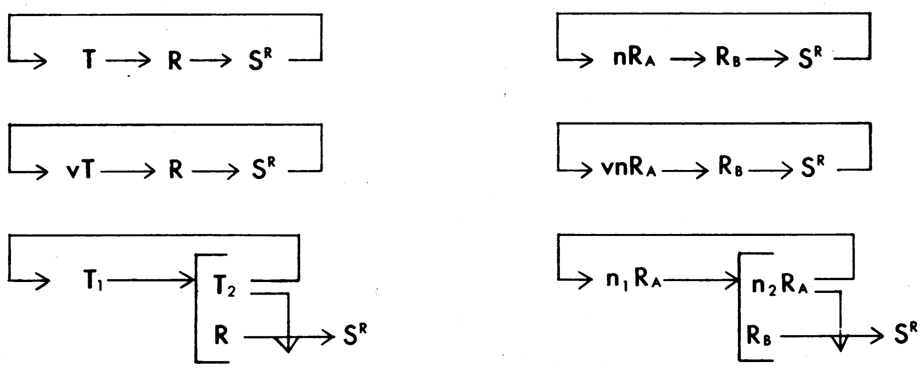
THE USE OF THE NOTATION SYSTEM FOR CLASSIFICATION

It was mentioned earlier that a symbolic notation such as the one proposed in this paper can facilitate the analysis and classification of behavioral procedures. One example of how the diagrammatic notation can reveal parallels between procedures is provided by a comparison of the diagrams for the DRL and the counting schedules:



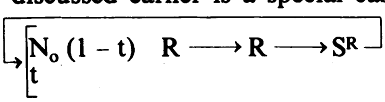
(20)

The only difference between the two diagrams is that the T of the DRL procedure is replaced by nR_A in the counting procedure. This parallelism suggests the possibility of exploring the response analogs of some other interval schedules as well. Such response analogs can be generated by substituting an nR_A term for every time interval, as in the following examples:

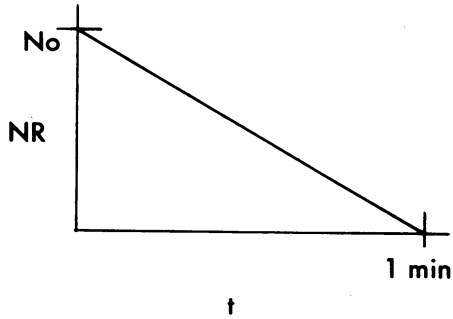


(21)

A comparison of the behavioral effects produced by these analogous procedures may well be of considerable interest.

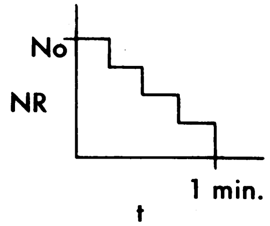
Two procedures can sometimes be diagrammed in such a way that one of them becomes a special, or limiting, case of the other. For instance, it can be shown that the alternative schedule (Ferster & Skinner, 1957) discussed earlier is a special case of the interlocking schedule described by the diagram 

. Here, t is the time that has elapsed since the last reinforcement, and N_0 is the number of responses required at time zero, that is, immediately after reinforcement. The number of responses required to bring about the R $\longrightarrow$ S^R condition at any time t is therefore N_0 (1 − t). The relationship between this number and the elapsed time can be shown graphically, as follows:



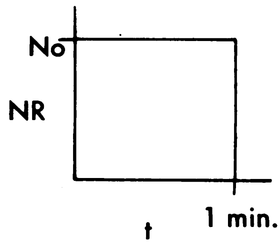
(22)

If the elapsed time t were treated as a quantized rather than as a continuous variable, this relationship would turn into a step function whose graphical representation would be:



(23)

If the size of the steps were now increased to the point where every step is an integral multiple of one minute, the graph becomes



(24)

and the diagram could be rewritten as $\rightarrow\begin{bmatrix} N_0(1-x) & R \longrightarrow R \longrightarrow S^R \\ x\ (1\ \text{min.}) & \end{bmatrix}$ where x stands for the number of 1-minute intervals that have elapsed since reinforcement. From time zero to one minute, the value of x would be zero; from one to two minutes, x would be one. Accordingly, the number of responses required to bring about the $R \longrightarrow S^R$ condition during the first minute is $N_0(1 - 0)$, or simply N_0. Thereafter, when the value of x is one or more, the required number of responses $N_0(1 - x)$ is zero. This means that the $R \longrightarrow S^R$ condition automatically goes into effect at the end of the first minute, and remains in effect until the reinforced response is made. This is, of course, the description of the alternative schedule. The form of its diagrammatic representation is the same as that of the interlocking schedule.

IV. *Conclusion*

The examples of diagrammed procedures presented in this paper were intended not merely as illustrations of the notation system's practical application, but also as tests of its ability to handle a broad variety of problems. The procedures were chosen not only for their saliency, but also for the diversity of the research areas from which they are drawn. It remains to be seen whether the assortment chosen was broad enough to give the system the versatility that will be required of it by its users. In case the proposed notation should prove inadequate in filling their needs, it may perhaps provide a starting point for the development of one that will be more equal to their demands. As was stated earlier, the present system should be regarded only as a first approximation. The construction of a generally useful system will require continuing interplay between design and application, as well as the collaboration of workers from the various provinces of behavioral science.

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